INEEL/CON-98-00258
CONF-980412--

"Multi-Agent Cooperative Systems Applied to Precision Applications"

M.D. McKay ^a, M.O. Anderson ^a, R.W. Gunderson ^b, N. Flann ^b, and B. Abbott ^b

^a Idaho National Engineering and Environmental Laboratory
P.O. Box 1625 / MS 2220 Idaho Falls, ID 83415

^b Center for Self-Organizing and Intelligent Systems
Electrical and Computer Engineering Department
Utah State University Logan, UT 84321

RECEIVED

MAR 27 1998

OSTI

ABSTRACT

Regulatory agencies are imposing limits and constraints to protect the operator and/or the environment. While generally necessary, these controls also tend to increase cost and decrease efficiency and productivity. Intelligent computer systems can be made to perform these hazardous tasks with greater efficiency and precision without danger to the operators. The Idaho National Engineering and Environmental Laboratory and the Center for Self-Organizing and Intelligent Systems at Utah State University have developed a series of autonomous all-terrain multi-agent systems capable of performing automated tasks within hazardous environments. This paper discusses the development and application of cooperative small-scale and large-scale robots for use in various activities associated with radiologically contaminated areas, prescription farming, and unexploded ordinances.

Keywords: Intelligent, Cooperative, Multi-agent, Robotic, Autonomous

1. BACKGROUND

Many hazardous activities require precise and delicate operations which human operators are unable to achieve without the aid of bulky, sophisticated equipment. Currently operators perform these activities, but recently the safety of operators has become the number one priority of all hazardous operations within the military, government, and industry. Regulatory agencies are imposing limits and constraints to protect the operator and/or the environment. While generally necessary, these controls also tend to increase cost and decrease efficiency and productivity. Intelligent computer systems can be made to perform these hazardous tasks with greater efficiency and precision without danger to the operators. The Idaho National Engineering and Environmental Laboratory (INEEL) and the Center for Self-Organizing and Intelligent Systems (CSOIS) at Utah State University (USU) have developed a series of autonomous all-terrain multi-agent systems capable of performing automated tasks within hazardous environments. The following is a brief review of several areas which greatly benefit from the use of these systems to reduce or remove workers from hazardous environments and perform demanding tasks with greater efficiency and precision.

1.1 Radiologically Contaminated Areas

The Secretary of Energy Federico Peña said "The Cold War left us a legacy of environmental contamination and degradation that will be with us for decades. Hundreds of millions of gallons of highly radioactive and toxic waste were generated while we produced the nuclear materials necessary for our national defense. Much of this waste contains long-lived radioactive elements that could pose risks for tens of thousands of years. Cleaning up this waste poses one of our greatest challenges" ¹. As such, the Department of Energy (DOE) is actively pursuing newer, safer, and more efficient methods to clean up the hazards left over from the cold war. These hazards range from decontaminating and dismantling nuclear reactors to indoor floor radiation characterization. Due to the hazardous nature of the contamination many systems are currently being researched for use in the massive clean up. Several systems have recently been developed by the DOE complex and are being bench marked or tested in radiation clean up

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

activities^{2,3}. Additional needs of the Department of Energy include the reduction or elimination of workers being exposed to radiation in surveillance and characterization activities in outdoor environments. These characterization activities range from deploying and scanning radiation sensors to soil sampling areas suspect of contamination due to leaching.

1.2 Prescription Agriculture

As farming throughout the world becomes more and more competitive, greater emphasis is being placed on maximizing yield while minimizing production costs. One method of accomplishing this, known as prescription agriculture, is through precise application of chemicals and fertilizers. Although prescription agriculture promises to provide these needed cost savings and yield increases, in order for prescription agriculture to become widely accepted many of the traditional soil care and testing methods must become more efficient and less labor intensive. For example, current methods of performing soil analysis includes multiple all-terrain vehicles (ATV), each carrying an operator with a differential global positioning system (dGPS), being disseminated to expert specified locations throughout a farmer's field to retrieve appropriate amounts of soil for constituent testing. Once soil testing is completed and an appropriate chemical prescription has been determined, sprayers traverse the farm applying the specified amounts of fertilizer. Additional prescription agriculture needs include obtaining topographical maps in an efficient manner and optimizing harvesting operations. The application of robotics and automation to these prescription agriculture activities can fulfill many of the technology needs while providing the necessary labor reductions and improving efficiency.

1.3 Unexploded Ordinances

Throughout the world there are numerous countries that suffer from areas which have been rendered useless due to unexploded ordinances (UXO). In order to clear unexploded ordinance areas, explosive ordinance disposal teams are required to physically perform a walk-through thus placing them in a hazardous situation. Some third world countries use the primitive method of paying a worker \$100 per day to wear a face shield and crawl on their belly in suspect UXO areas while pressing a stick into the ground hoping to locate (not detonate!) the unexploded munitions. UXO is definitely an example of a hazardous operation and one that benefits from technology advancements in cooperative robotics and precision automation. National programs are in place to research the application of cooperative robotics to UXO. One such program is BUGS, Basic UXO Gathering System, which is aimed at developing, testing, and evaluating the use of multiple small robots in neutralizing unexploded ordinance⁴. Application of the INEEL-USU developed multi-agent systems to the BUGS program will be discussed later in this paper.

2. DEVELOPMENT AND APPLICATION OF COOPERATIVE SMALL-SCALE ROBOTS

In 1996, under a University Research Consortium grant from the INEEL, Utah State University developed the ARC-III small-scale robot. The ARC-III is a small, approximately 18"x12"x12", six-wheeled highly maneuverable robotic vehicle. Each of the six wheels is completely independent of the remaining wheels, with its own power supply mounted inside the wheel hub along with a Motorola 68332 based controller board used to control two dc-motors; one acting as the forward drive motor, the other for turning. A unique optical slip ring allows two-way communication by the wheel controllers with a single 68332 control node located in the chassis instrumentation bay. The optical slip ring permits each wheel to be rotated through full 360-degree motions without physical constraints, resulting in ultra-maneuverability duplicating that of a humming bird restricted to planar flight. Placing the rechargeable power supply for each wheel in the lower half of its wheel hub provides a very low center of gravity and excellent stability even with up to 5kg payload mounted in the chassis instrumentation bay. A differential chassis suspension system helps to mechanically self-level the instrumentation bay. Figure 1 shows the ARC-III vehicle.

Figure 1 ARC-III

The ARC-III is designed to participate in individual missions or multi-agent missions. Coordination of these activities is accomplished through a central computer control station running an optimal mission and path-planning algorithm. The details of this algorithm are available in the Incremental A* Algorithm paper by Flann⁵. In summary, the problem is partitioned into two simpler problems. The first involves navigating a single vehicle to a single goal, and solved using a dynamic A* algorithm. The second problem involves determining near-optimal tours for the multiple vehicles to minimize total mission time. This is done by generating the initial tours through heuristic methods, and then incrementally repairing the tour as new information is gained by vehicles operating in the environment. After the near-optimal tours are generated, each vehicle is given a sequence of goals to visit, with the dynamic A* algorithm used to plan the paths between goals. The control station also provides a graphical user interface (GUI) allowing goals / missions to be interactively specified by the user. Figure 2 shows a screen capture of the GUI executing a real-time characterization mission on the Idaho Chemical Processing Plant (ICPP). In this scenario, two ARC-III vehicles are used to identify and clean up simulated radiological contamination. One ARC-III is used to precisely survey for contamination while relaying position and sensory data to the central control station. As "hot spots" are identified, the path-planning algorithm identifies optimal paths for the second ARC-III to traverse and a clean up mission is initiated at the precise location identified by the first ARC-III.

Figure 2 Idaho Chemical Processing Plant Mission

During the development of the ARC-III for hazardous environments it was identified that this technology could prove to have a dual use capability in precision agriculture by relieving some of the intense labor requirements. It was decided that a dual use presentation of the ICPP hazardous environment and a small-scale agriculture site would be demonstrated at the 1996 INEEL Site-Specific Technologies for Agriculture Field Day. During this presentation enough interest was generated by local and national experts to justify combining requirements from hazardous environments and prescription agriculture into the specification for the next generation of large-scale robotic vehicles.

3. DEVELOPMENT AND APPLICATION OF COOPERATIVE LARGE-SCALE ROBOTS

Performance criteria and design specifications for the large-scale systems needed to allow the dual use of the technology in hazardous and agricultural environments. Fortunately, the needs of each area are virtually the same. For example, the automated vehicles in both cases must be capable of sustained operation at very low speeds, as well as more rapid movement between distant application sites. The vehicles must also be highly maneuverable, similar to the capabilities of the ARC-III, and able to transport significant payloads of sensors and application devices such as soil samplers and boom sprayers.

After spending considerable time and effort carefully surveying the commercial market, the combined INEEL-USU team concluded that the Canadian developed Triton Predator all-terrain vehicle, shown in figure 3, best satisfied all of the criteria and specifications. The Predator is an eight-wheel drive amphibious vehicle featuring a hydrostatic drive system. It is fairly large, with length 114.5", width 60", and height 33". It is terrain robust, with a very stable design and a grade capacity of 45 degrees. It is powered by a 25 hp Kohler, 90 degree V, twin cylinder overhead valve engine, and weighs 1000 lbs. unloaded with a gross weight capacity of 2000 lbs. Maximum speed on a zero grade is 22 mph. During the industry search it was determined that the Predator is the only commercially available ATV which possessed a hydrostatic drive system. These, and its ability to execute an on the spot 360-degree turn, were considered essential features. Two Predators were converted to allow the capability of either manual remote RF control or fully autonomous computer control suitable for individual or cooperative missions.

Figure 3 Triton Predator

In conjunction with the 1997 INEEL Site-Specific Technologies for Agriculture Field Day held at the Hess farm in Ashton, Idaho, the two computer-controlled Predators were outfitted with soil sampling and spraying systems. An arch-info map of the Hess farm was integrated into the path and mission planing software and the GUI expanded to allow user-specified cooperative missions consisting of visit-site, soil-sample, or sweeping (see figure 4). This set-up was then utilized to demonstrate the individual and cooperative capabilities of the intelligent computer controlled systems for use in agriculture and hazardous applications. The predator outfitted with the soil sampling equipment proved to be of particular interest during the field day. At the conclusion of the presentation the field, where repetitive soil-sampling missions were conducted, was inspected and found to have numerous holes all within a few centimeters of one another. Figure 5 shows INEEL Robotics manager Ron Lujan covering multiple samples points with a single hand. The capability of the autonomous computer controlled system to precisely and repeatedly maneuver the large-scale robots had been demonstrated.

Figure 4 Cooperative Missions at Hess Farm

Figure 5 Precise Soil Samples

4. APPLICATION OF TEAMS OF COMBINED LARGE & SMALL SCALE ROBOTS

Efforts for 1998 include continuing the dual use of these cooperative robots applied to hazardous and agriculture environments as well as expanding to applications associated with unexploded ordinance. In the paper by Nguyen, et al. ⁴, various control methodologies are discussed in resolving the UXO problem. In particular the statement is made, "It is important to select a multiple-robotic system approach that is reliable, economical, and robust enough to operate in an unknown environment." Two methodologies discussed in this paper are multiple-robots with assisting operator control unit and multiple-robots with assisting asset. In the first methodology, the concern of coordination of complex tasks between different vehicles is discussed and the use of a central operator control unit is presented as a viable solution to this problem. The operator control unit is used to collect data and provide map guidance and operator interface for the multiple-robots. In the second methodology, a sophisticated, highly intelligent, sensor platform is proposed which allows for centralized coordination between smaller, simpler and inexpensive robots. The simpler robots are used for activities where the probability of loss increases, such as mine detection or detonation.

In keeping with these two methodologies, the INEEL-USU team is developing a strategy utilizing all three components of the multi-agent cooperative scheme - small-scale robots, large-scale robots, and the central control station running the mission and path-planning software. INEEL has gained expertise in this form of cooperative assisted robotics during the DOE Multiple Automated Characterization System and Reduced Access Characterization

System project³. A scheme similar to that employed between the large floor characterization system, reduced access floor characterization system, and the central control station will be used. Current efforts are aimed at reducing the ARC-III vehicles to the described simple, inexpensive multi-agents suitable for mine detection and detonation. These simplified robots will be capable of conducting hunting missions using dead reckoning and low-cost positioning sensors. Additionally, the Predator will become the sensor-rich, intelligent assistant described above capable of transporting ARC-IIIs to distant remote sites, interfacing to the central control station, and assisting multiple ARC-III vehicles in precise positioning once an unexploded ordinance has been identified. Finally, the mission and path - planning software will serve as the operator control unit allowing central data collection, map creation and tracking, and an interface to the sensor-rich Predator as well as each low cost ARC-III. The power of this scheme is the ability to scale to the appropriate level for the complexity of the mission. For example, two sensor-rich Predators could be deployed to separate sites each carrying multiple simplified ARC-III vehicles. As unknown areas of the environment are encountered and possible mission failure could occur, the capabilities of the optimal mission and path-planning algorithm can be employed to restructure the mission and maximize the probability of success.

5. ACKNOWLEDGEMENTS

INEEL's Academic and Professional Affairs Department provided research funding for this project through manager Debonny Shoaf with University Research Consortium staff Radean Wilcox and Laboratory Directed Research and Development staff Diana Skoy and Steven Piet. The authors would like to recognize the contributions of other participants in this effort including Monte Frandsen, Mel Torrie, Eric Poulsen, Gordon Olsen, Major Peter Van Wirt, Bret Hancy, Marc Oliver, Don Cripps, and John Jacobs. A special thanks to Steve Smith of Trimble Navigation Limited for the loan of dGPS equipment.

6. REFERENCES

1. U.S. Secretary of Energy Federico Peña, "Prepared Remarks for Department of Energy Budget Roll-out", Washington, D.C., February, 1998.
2. Anderson, M.O., McKay, M.D., and Willis, W.D., "The VirtualwindoW for Nuclear Applications", proceedings of the ANS Seventh Topical Meeting on Robotics and Remote Systems, Augusta, Georgia, 1997.
3. Anderson, M.O., McKay, M.D., and Richardson, B.S., "Multirobot Automated Indoor Floor Characterization Team", proceedings of the IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota, 1996.
4. Nguyen, T.N., Debolt, C., Freed, C., Nguyen, T.B., "BUGS: Multiple Robots Approach to UXO & Mine Field Neutralization", proceedings of the U.S. Department of Defense UXO conference, May, 1997.
5. Flann, N., "Path Planning for Large Structured Environments: the Lazy Incremental A* Algorithm", Utah State University Center for Self-Organizing Intelligent Center meeting, Logan, Utah, 1996.